Shear Localization in Tantalum Top Hat Samples

Curt A. Bronkhorst and Paul J. Maudlin (T-3), and Ellen K. Cerreta, Thomas A. Mason, and George T. Gray III (MST-8)

The ductile failure process for polycrystalline metals is a sophisticated sequence of physical events occurring at different length scales. One element of that process is believed to be shear localization and subsequent shear band formation. In general, the shear localization process involves initiation and growth where initiation is expected to be a stochastic process in material space where anisotropy in the elastic-plastic behavior of single crystals and intercrystalline interactions serve to form natural perturbations to the material's local stability. A common sample geometry used by the Structure/Property Relations group in the Materials Science and Technology Division (MST-8) to study shear localization growth is the "top hat." As the name implies, it is an axisymmetric sample with an upper "hat" portion and a lower "brim" portion with the gage section between the hat and brim. Figure 1(a) shows one-half of the cross-sectional geometry (line of symmetry along Z-axis) for a typical sample. The gage section length is generally on the order of 0.9 mm. The samples were deformed in a Split-Hopkinson Pressure Bar system at maximum top-to-bottom velocity in the range of 10–25 m/sec. We have attempted to model these experiments through both continuum and polycrystal plasticity finite element models.

Experimental and continuum model results for an initial sample temperature of –100˚C can be found in Figs. 1 and 2. Figure 1 shows contour plots of equivalent plastic strain at 50 µsec after the wave hits the hat. Figure 2 shows the mean top surface traction applied to the sample during loading.

For the continuum model, the finite element code EPIC was used with a Mie-Grüneisen equation of state and the rate and temperature sensitive MTS flow stress model. Adiabatic conditions were assumed. The numerical results suggest a maximum strain rate on the order of $10^5\ s^{-1}$ in the gage section. The model also suggests that a temperature in the neighborhood of 800˚C is reached within the gage section due to the substantial plastic deformation (up to 500%), which takes place over a small period of time.

Using a polycrystal plasticity approach we are attempting to link the localization behavior of these samples to the crystallographic characteristics of tantalum. Figure 3 shows shear stress results of simulations where groups of elements were used to represent a single crystal, each group with a different initial crystallographic orientation. A total of 127 crystals spanned the gage section region. The finite element code ABAQUS along with a rate and temperature-dependent crystal plasticity model was used. The crystal plasticity model allowed for slip to occur on the twelve {110}⟨111⟩(and twelve {112}⟨111⟩ slip systems. The model determined active slip systems based upon loading conditions and crystallographic orientation. Figure 3 shows the high level of heterogeneity that one might expect in the sample gage section for a polycrystalline material. The shear stress contour results suggest a factor of three difference between high and low values.

For more information, contact Curt Bronkhorst (cabronk@lanl.gov).

Acknowledgements

We would like to acknowledge NNSA's Advanced Simulation and Computing (ASC), Materials and Physics Program, the Joint DoD/DOE Munitions Technology Development Program; and Campaign 2, Dynamic Materials Properties, for financial support.

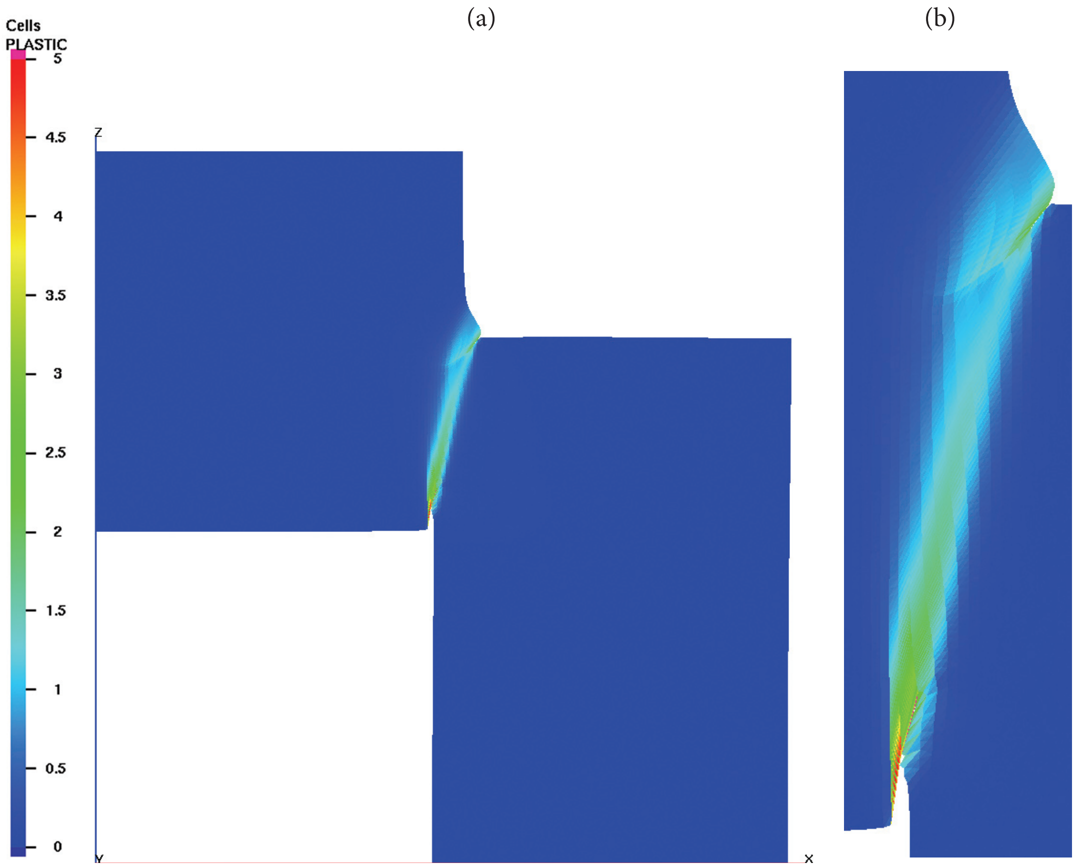

Figure 1—
Total equivalent plastic strain at a time of 50 μsec for an initial temperature of –100˚C; (a) axi-symmetric continuum model; (b) gage section only.

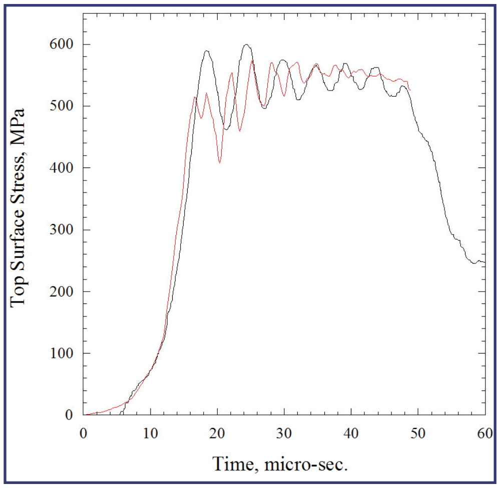

Figure 2—
Experimental (black) versus continuum simulation (red) top-surface stress response for an initial sample temperature of –100˚C.

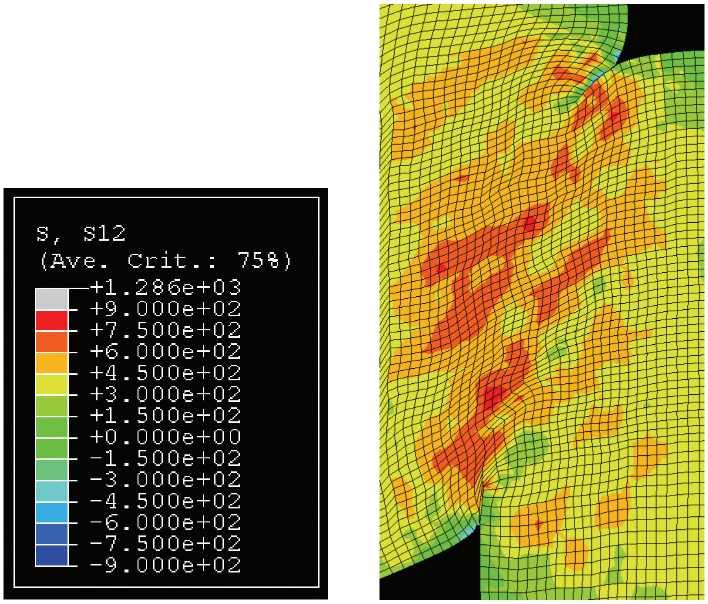

Figure 3—
Shear stress within the gage section of a polycrystal plasticity simulation.

Los Alamos
NATIONAL LABORATORY
EST. 1943